Technology Challenges & Chemicals

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Agenda

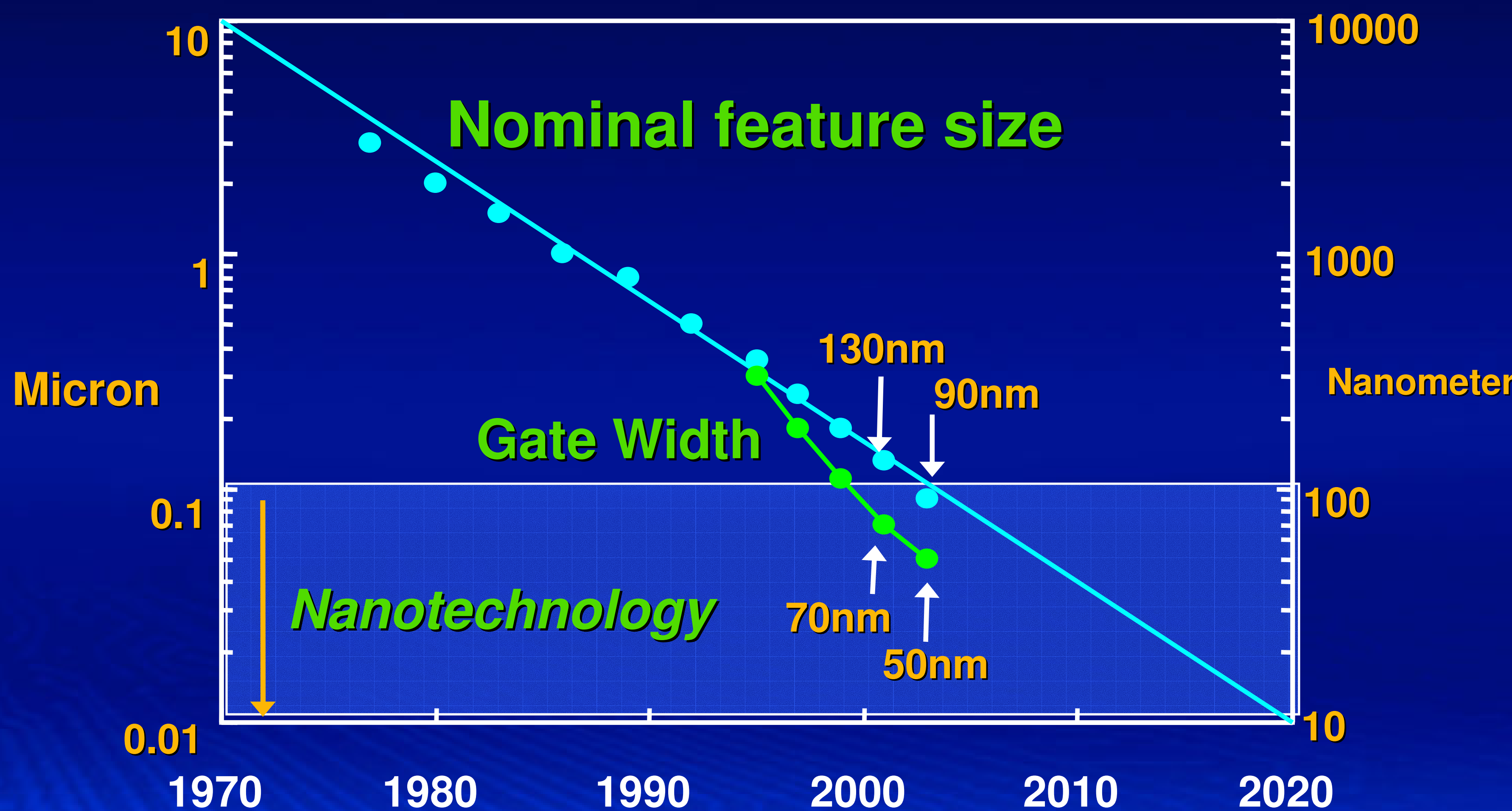
- Technology Scaling and Moore's Law
- Technology Challenges
- Chemical & Nano-material Opportunities
- Summary

Key Messages

- Silicon Nanotechnology is production reality and follows Moore's law
- New materials are needed for future technologies
- Molecular innovation will be required for new materials
- Nanotechnology could play a role in molecular innovation…

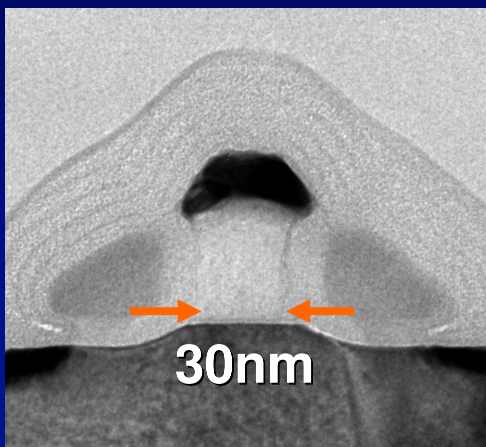
Need innovative material solutions

Technology Scaling

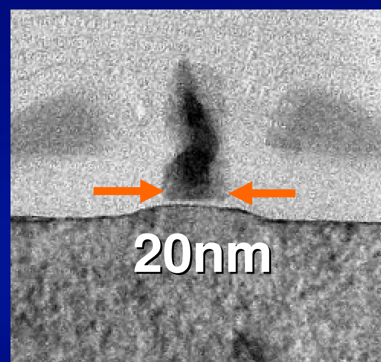


Intel’s Transistor Research in Deep Nanotechnology Space

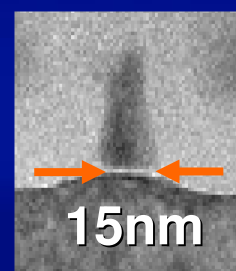
Experimental transistors for future process generations



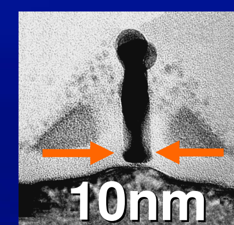
65nm process
2005 production



45nm process
2007 production



32nm process
2009 production



22nm process
2011 production

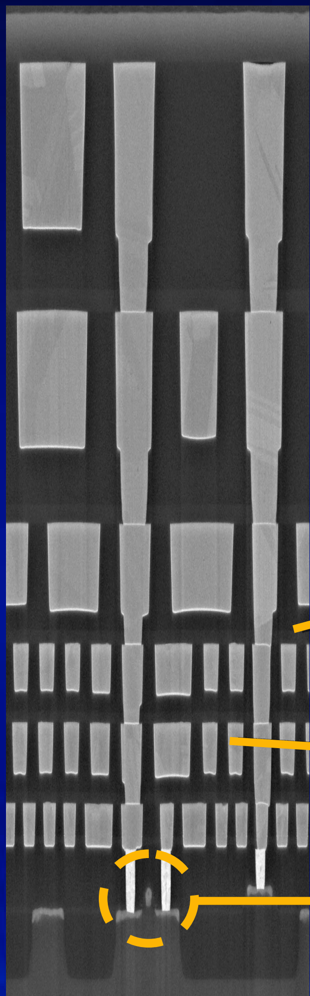
Transistors will be improved for production

Source: Intel

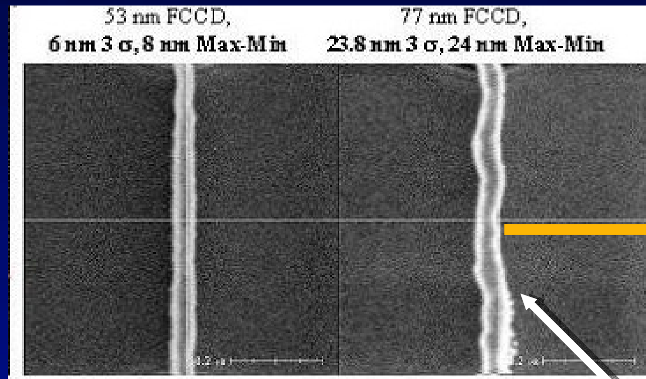
Silicon Scaling Leads to Material Challenges

- **Lithography**
- **Transistors**
- **Interconnects**

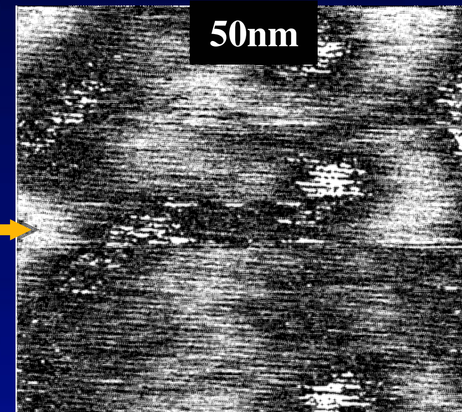
Material Challenges



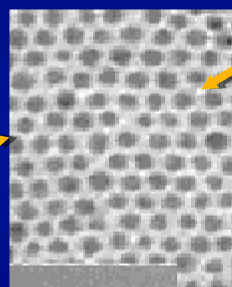
PPT Shrink
Source: Intel



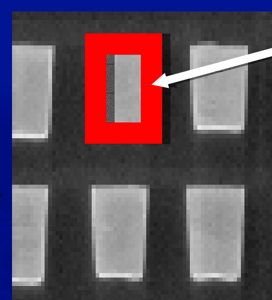
Print Features Line Edge Roughness(LER)



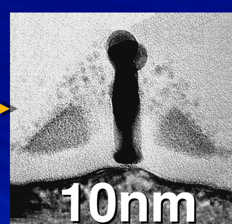
Resist Nano-domains



Low K Interlevel Dielectric
Micelle Assembled….



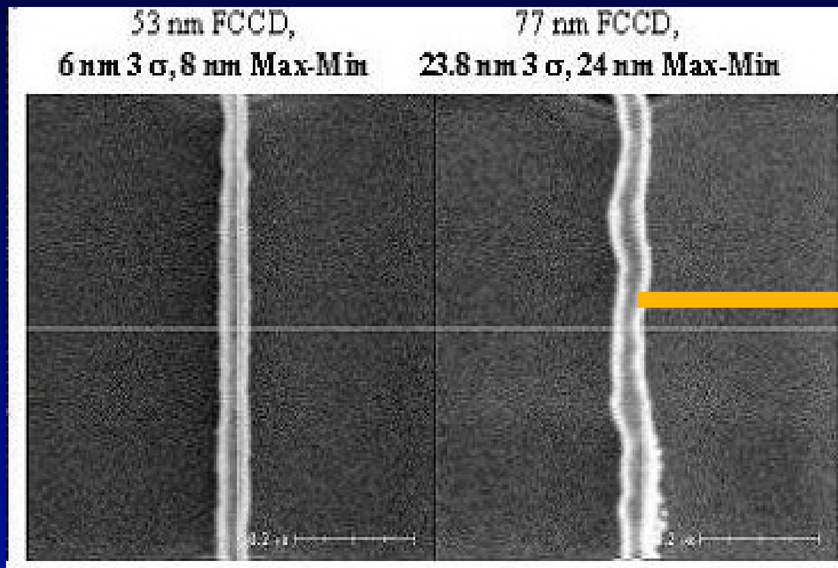
Barrier Layer ~20nm



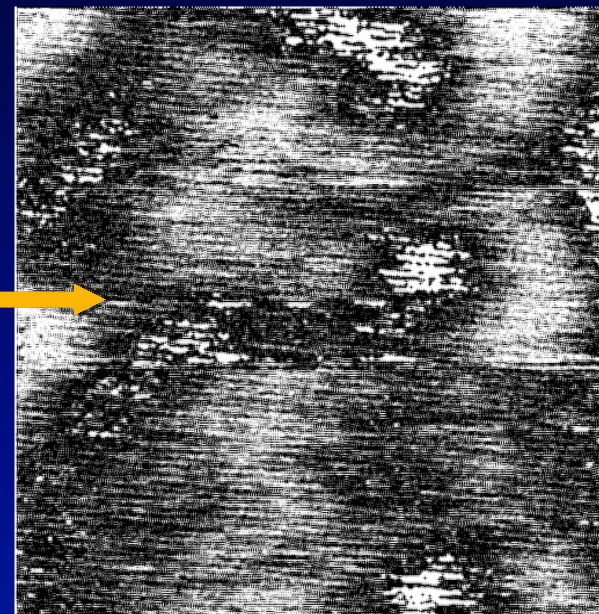
What Device Next?
What Materials?
How to Assemble?

Materials Challenges Everywhere

Future Lithography Resist Challenges



Line Edge Roughness(LER)



Atomic Force Microscope Picture of Resist Nano-domains

- **Resist nano-domains limiting feature resolution and defects.**
  - ***Requires control at the molecular level***
  - ***New chemicals required for future resist….***

New Materials, Devices Extend Si Scaling

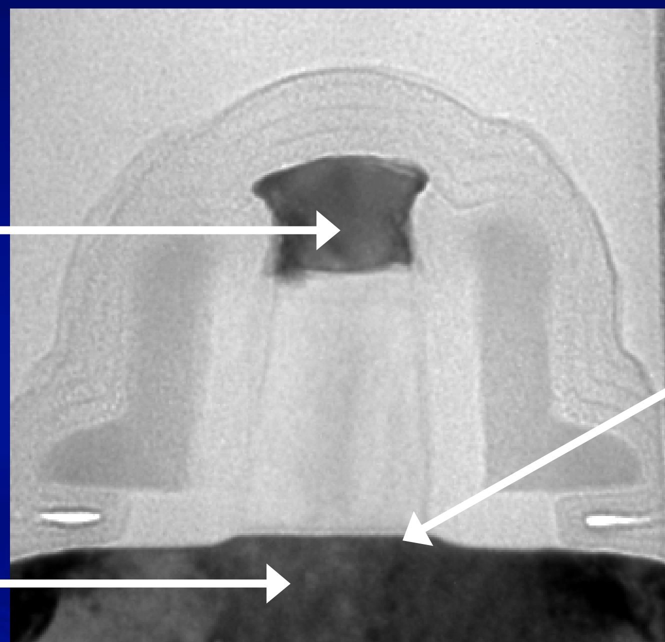
Changes Made

Gate

Silicide added

Channel

Strained silicon

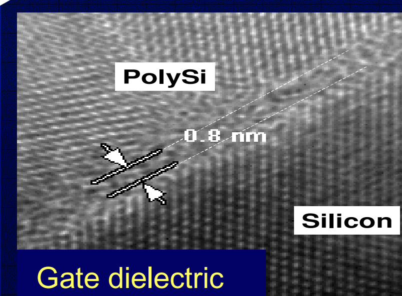


Transistor

Source: Intel

Future Options

High-k gate dielectric

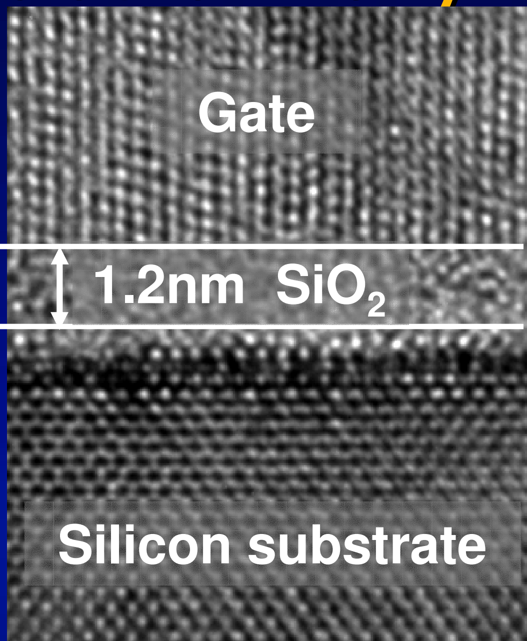


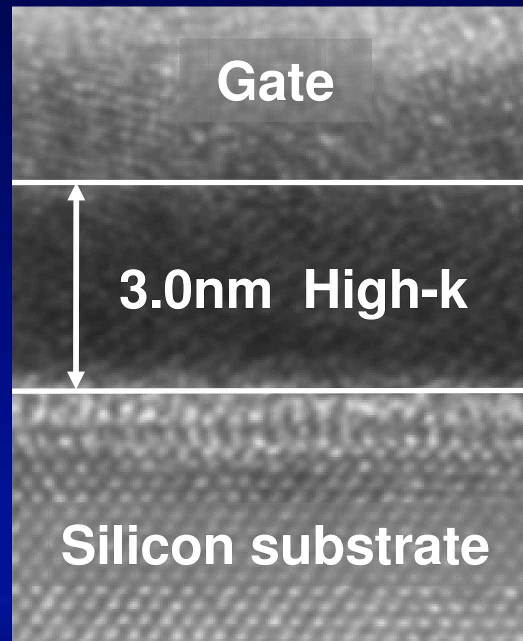
Gate dielectric less than 3 atomic layers thick

Source: Intel

New Materials Required for Gate & Gate Dielectric

High-k Dielectric reduces leakage substantially



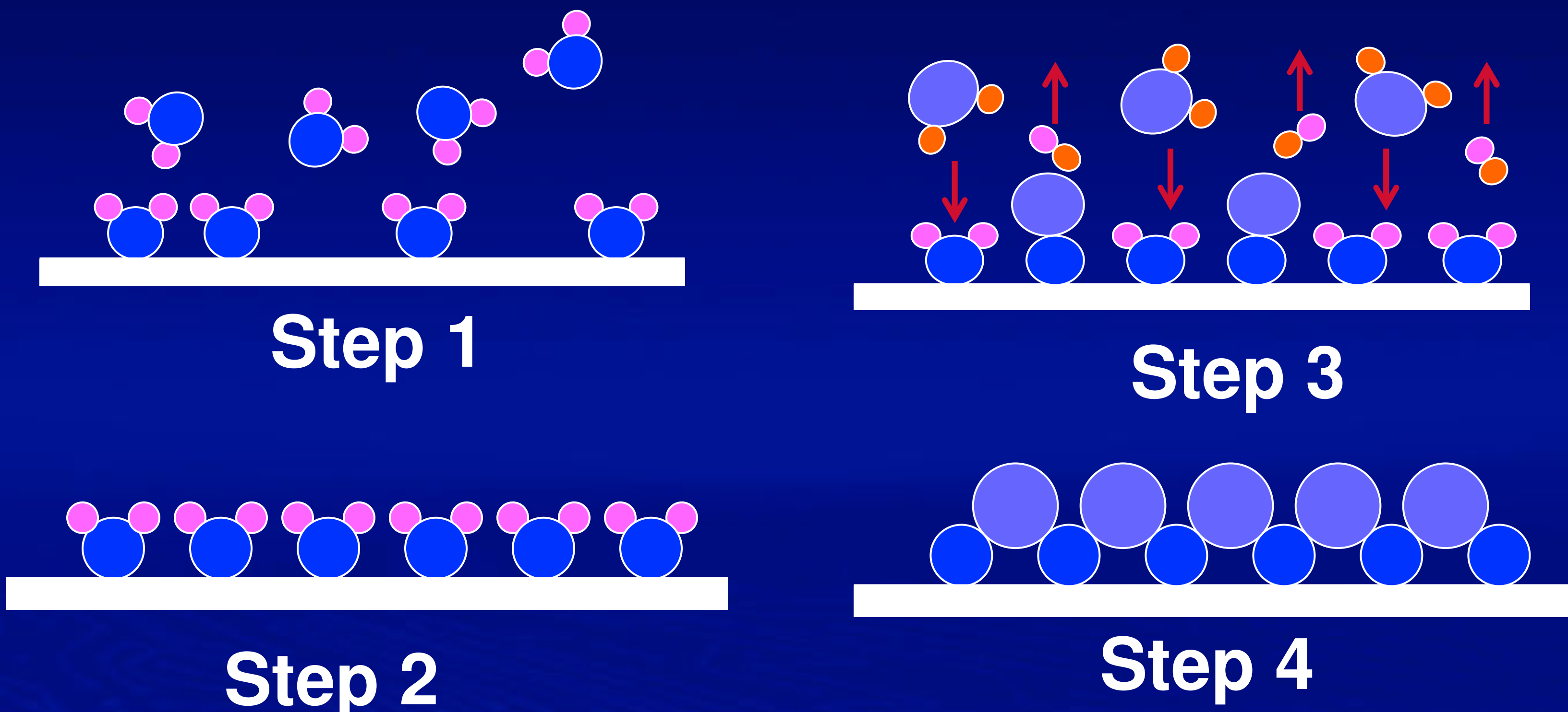


Robert Chau, Nov., 2003

<u>Benefits compared to current process technologies</u>

	High-k vs. SiO_2	Benefit
Capacitance	60% greater	*Much faster transistors*
Gate dielectric leakage	> 100x reduction	*Far cooler*

High-k Materials Require New Manufacturing Techniques



High-k Materials Are Deposited One Molecular Layer at a Time
Precursors must be Designed for Monolayer Assembly

New Materials, Devices Extend Si Scaling

Changes Made

Metal lines

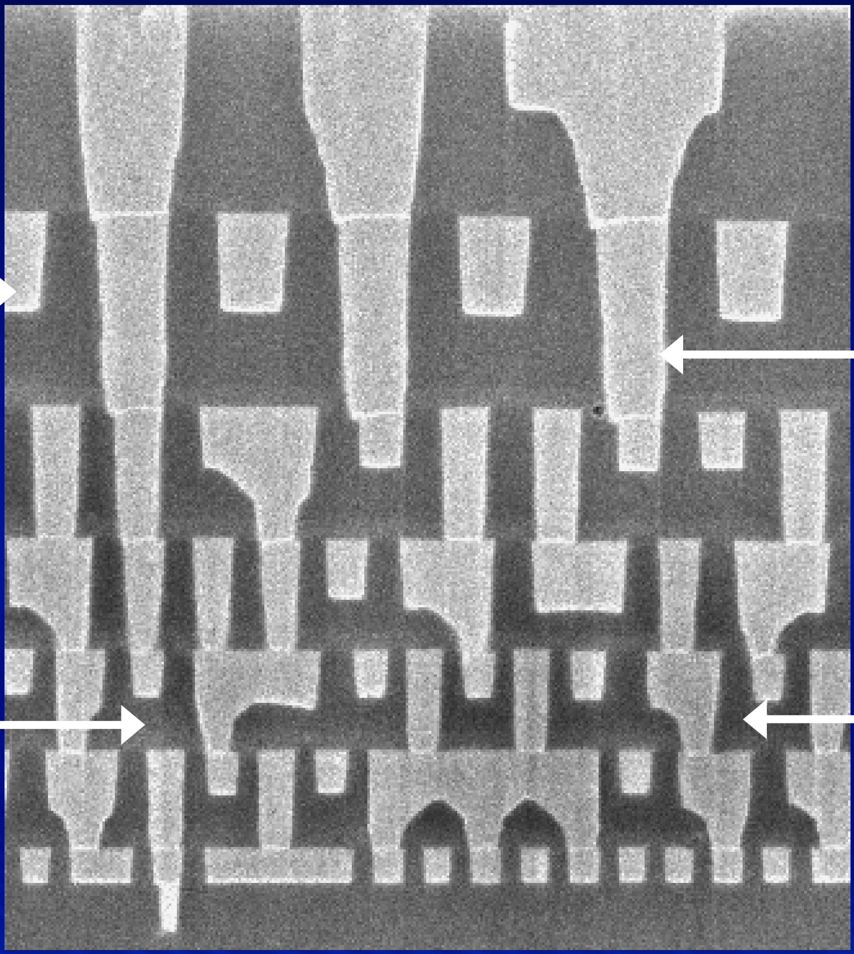
Al → Cu

Insulating dielectric

SiO_2 → SiOF

→ CDO

(low-k)



Interconnects

Source: Intel

Future Options

New Thinner Barrier Layers

Ultra Low-k Dielectric

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ILD Challenge: k<2.4

- Materials must meet complex requirements
  - K<2.4
  - Acceptable mechanical strength
  - Compatible with processing
- Most viable materials are nano-porous, but no winners
  - CVD
  - Self-Assembled spin-on materials
  - Need Closed Chemically Stable Pores

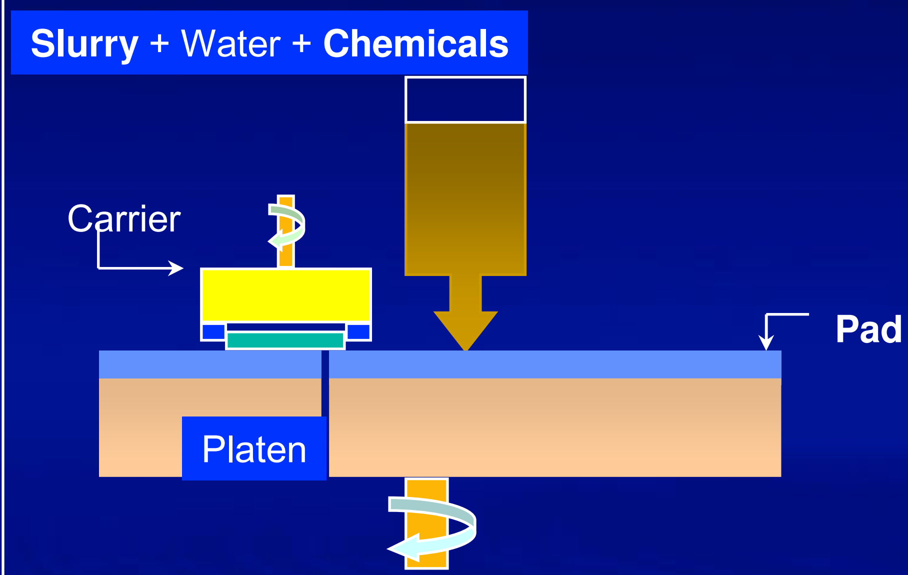
Need precursors that produce stable nano-pores & properties…

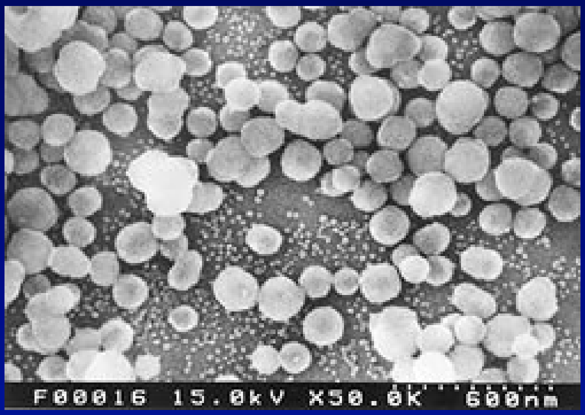
Interconnect Challenges

- Barrier Layer
  - → Reduce thickness
  - → Compatibility with low K ILD
  - → Effective diffusion barrier
  - → Good resistivity
- Interconnect Materials
  - → Improve effective resistivity (surface, etc)
  - → Improve electromigration
- Many Materials Challenges

Chemical Mechanical Polish

Chemical Mechanical Planarization (CMP)



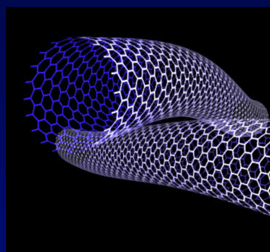


100nm-200nm
Slurry Particles

•CMP Slurry particles approaching nano-scale

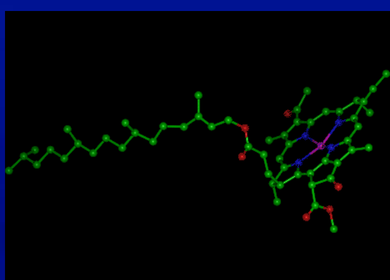
•**New materials may require new process chemicals**

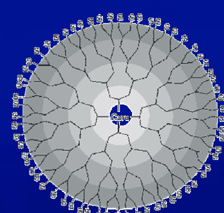
Nanotechnology Examples



Sub 100nm particles

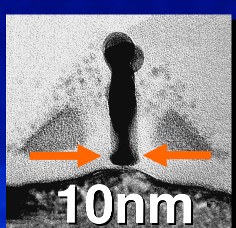
Molecular Assembly (directed and self assembly)





Dendrimers

Macromolecules



Sub 100nm structures

Future Requirements

- Many new materials will be required for Silicon Nanotechnology
- New chemicals & nano-materials have opportunities, but significant challenges
  - ➔Control & reproducibility of properties
  - ➔Purity
  - ➔Metrology
  - ➔Controlled assembly into useful forms
  - ➔Ability to make electrical & thermal contact
  - ➔Environment Health & Safety
  - ➔Cost

Summary

- Many new materials required for future technology
- New materials will be needed
- Innovative chemical will be required…
- Nanotechnology may provide new materials, but has significant challenges

Molecular Innovation is Needed…..

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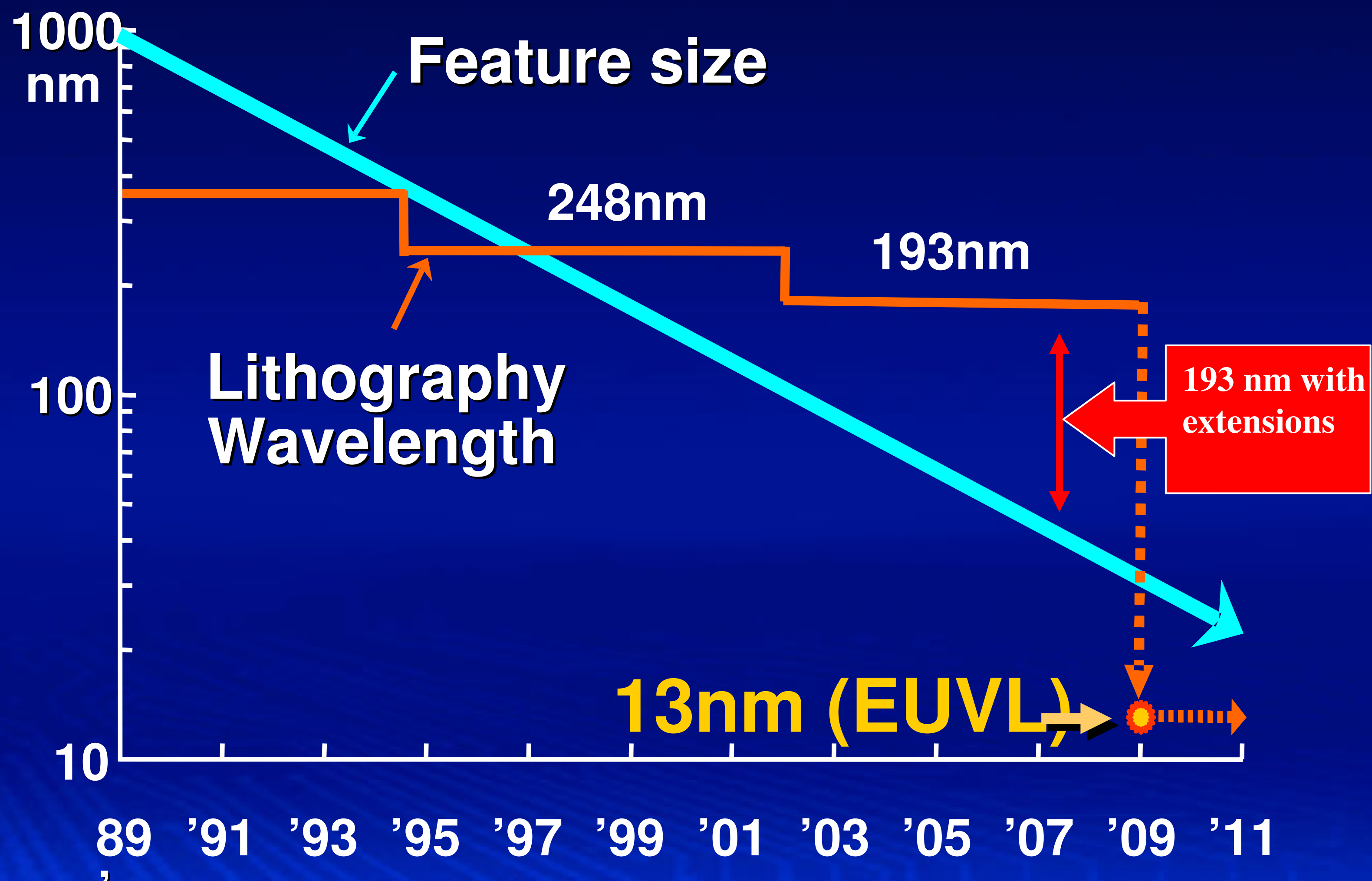
For further information on Intel's silicon technology and Moore’s Law, please visit the Silicon Showcase at www.intel.com/research/silicon

Back-up

Lithography Challenge



New Mask, Design Techniques, and Materials Needed to Support future Lithography Scaling